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DEVELOPMENT OF PVF2 LIGHTWEIGHT PORTABLE LOUDSPEAKER.(U)

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DEVELOPMENT OF PVF_2 LIGHTWEIGHT PORTABLE LOUDSPEAKER

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September 1979

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Loudspeaker delivers 85 db SPL at one meter and weighs less than one pound. Designed to operate in conjunction with portable radio sets such as PRC-70.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A PVF_2 Loudspeaker is described which is very lightweight and delivers 85 dB SPL across the 400-4000 cycle audio band, for use with radio sets AN/PRC-77 and AN/PRC-70 which provide the signal and power for the transducer. The diaphragm is made of 4 sheets of PVF_2, a piezoelectric film with both sides coated with a thin aluminum film which was found to be very unstable in → next page

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20. ABSTRACT (continued)

handling and flaking in humidity. The diaphragm presents a capacitive load to the amplifier requiring considerable power from the radio batteries, therefore, the loudspeaker is considered not suitable for man-pack battery operation.

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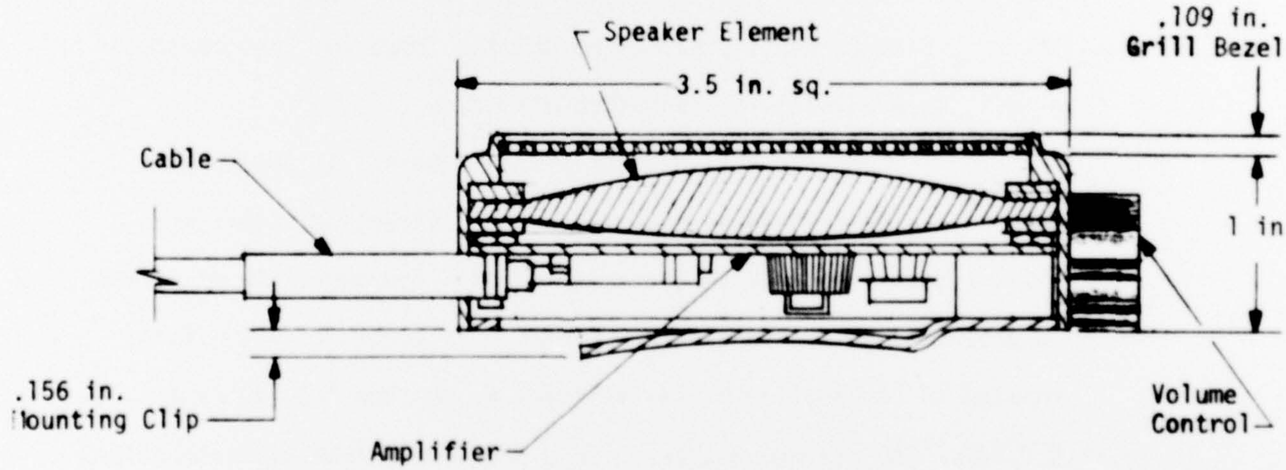
1.0 PURPOSE

The purpose of this development program was to design a loudspeaker using a film of polyvinylidene fluoride (PVF_2) as the electro-acoustic transducer which would derive its signal and primary power from a backpack radio such as the PRC-70. The size was specified to be 3-1/2 x 3-1/2 x 1 inches with a weight of less than one pound. The required acoustic output was 85 dB SPL between 500 and 2000 Hz at a distance of one meter. The result of the program was a loudspeaker which approximates the performance requirement but is inherently inefficient in regard to primary power consumption.

Figure 1 is a cutaway view of the loudspeaker.

CUTAWAY OF PVF_2 SPEAKER



Note: All components are not shown on amplifier board.

FIGURE 1

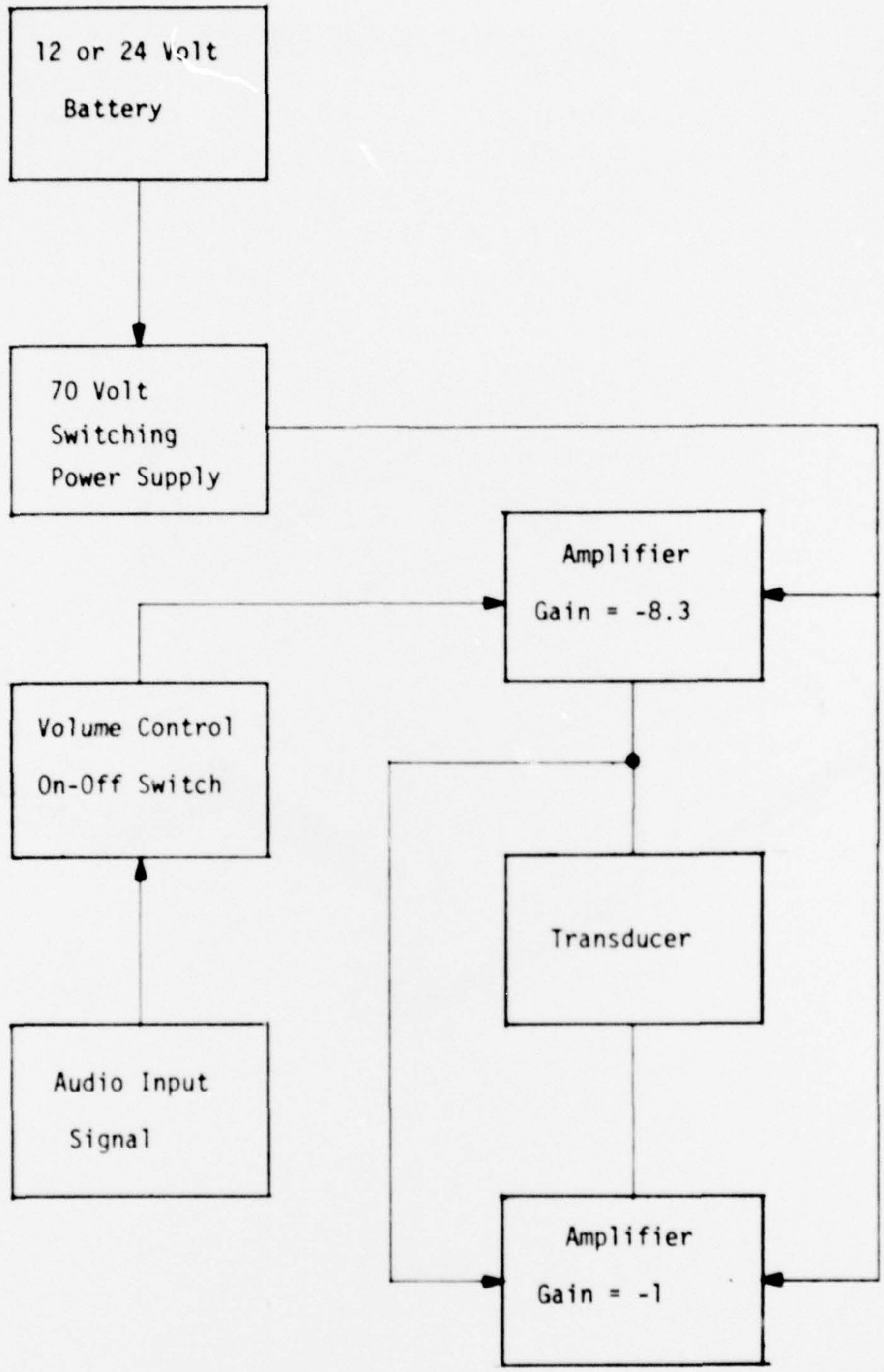
2.0 SPEAKER SYSTEM DESIGN

The speaker system consists of a high efficiency switching power supply which is capable of operating from either 12 or 24 volt power supplies, a pair of bridged amplifiers, a volume control on-off switch, and a thin film piezoelectric speaker. The electrical system and transducer are packaged in a 3.5 inches square by one inch enclosure with a harness clip and low profile thumbwheel volume control knob. A block diagram of the design is shown in Figure 2.

2.1 Transducer Design

The transducer consists of four piezoelectric thin film elements approximately 8 cm square and polyurethane foam spacers and suspension shown in Figures 3 and 4. Each piezoelectric element is a seven micron thick polyvinylidene fluoride (PVF_2) film. The film expands and contracts proportionally to the applied signal. The PVF_2 film elements provide the driving force for the transducer as well as providing the radiating diaphragm.

Consider a film whose plane is normal to the z axis. When an electric field is applied in the z direction across the film, a strain results in the x direction. The magnitude of strain is proportional to the electric field. The electric field, E, is related to the applied signal voltage, V, and the film thickness, d, $E = V/d$. The maximum electric field and the maximum acoustic output is obtained by using film of minimum thickness.



SYSTEM BLOCK DIAGRAM

FIGURE 2

PVF$_2$ SPEAKER ELEMENT ASSEMBLY

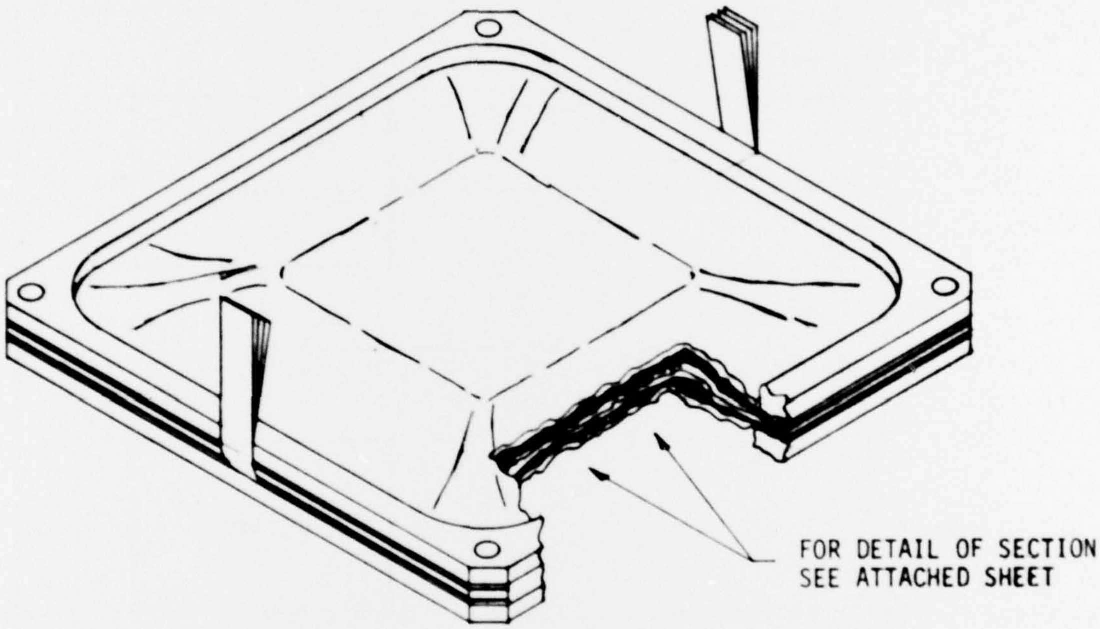
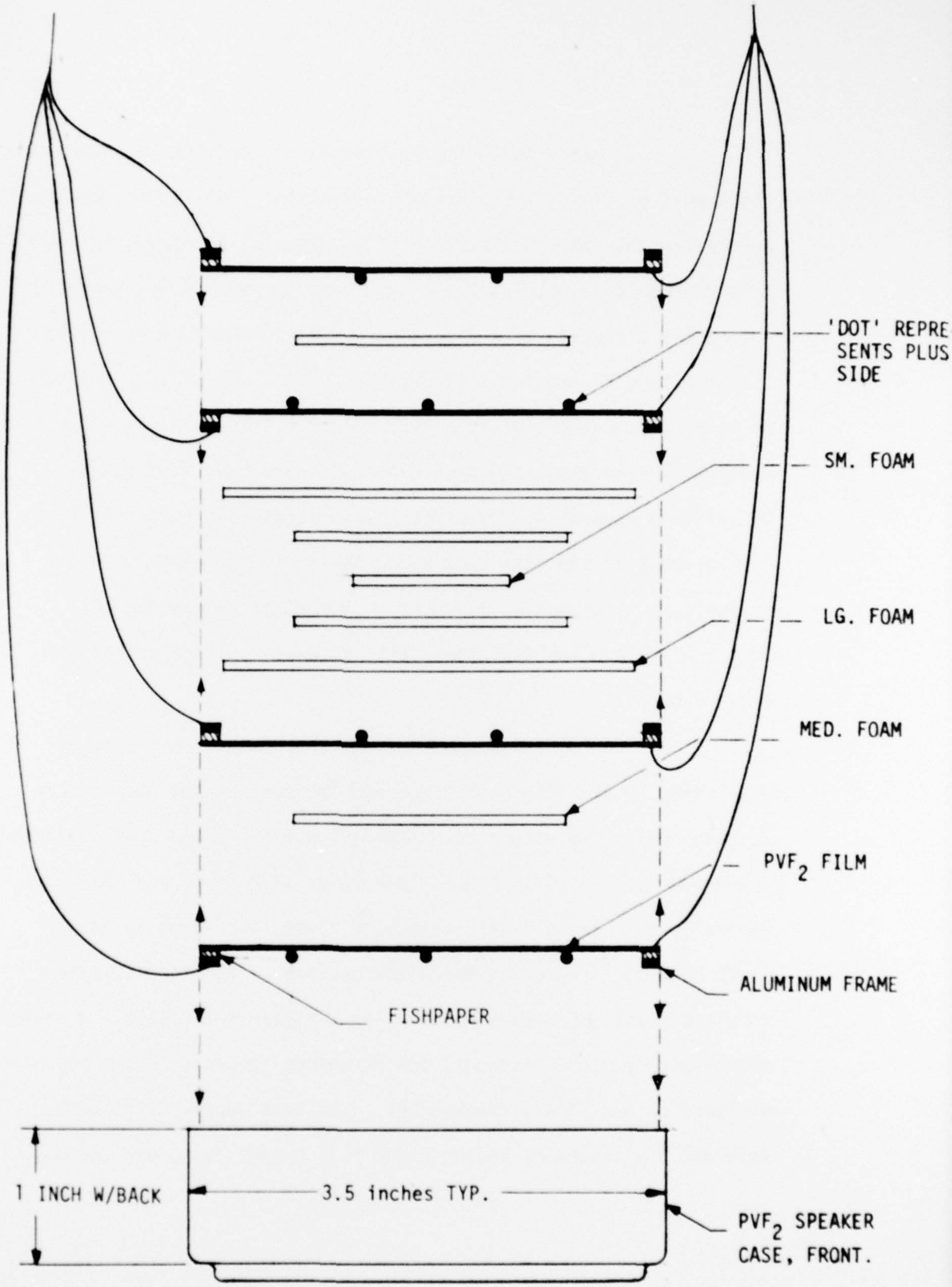


FIGURE 3



'DOT' REPRESENTS PLUS SIDE
SM. FOAM
LG. FOAM
MED. FOAM
PVF_2 FILM
ALUMINUM FRAME
FISHPAPER
1 INCH W/BACK
3.5 inches TYP.
PVF_2 SPEAKER CASE, FRONT.

FIGURE 4

In order to obtain an acoustic output from the speaker there must be film motion in the z direction. This is accomplished by shaping the film as a section of a spherical surface. As the film expands and contracts, the spherical surface is displaced in the radial direction or z direction normal to the surface of the film creating an acoustic disturbance. The z motion is reinforced by an arrangement of multiple piezoelectric film elements. Two elements are arranged around a convex polyurethane foam spacer. One element expands as the other element contracts resulting in a displacement of the foam spacer and the two film elements in the z direction. The motion is reinforced further by placing thin foam spacers and two additional film elements outside of the two inner elements.

The low frequency limit of the speaker is primarily determined by the film compliance and the mass of the foam spacer. In this design, we used a foam with a low density and low compliance. There are foams available which are lower in density but these are higher in compliance. Utilization of those lower density foams would have required using more foam because of the foam's higher compliance and would have resulted in a higher total mass. A higher mass would result in extended low frequency response at the expense of lower output at all frequencies. The best approach for both extended low frequency response and high output is to use the most

compliant film available and to minimize mass. The film compliance is inversely proportional to its thickness. Therefore, one must use the thinnest available film with a very low density, low compliance foam spacer.

2.2 Power Supply Design

The power supply is shown in Figure 5. The objective of the design is to supply a 70 volt DC output from a 12 or 24 volt input with maximum efficiency. A CMOS quad 2 input nand gate is used as a multivibrator. Q_1 is the driver for the power switching transistor, Q_2. When Q_2 is on, current in L_1 increases and energy builds up in the magnetic field stored in the coil. When the power switch (Q_2) is switched off, the coil's energy is transferred into the storage capacitor, C_2. As the voltage increases above the regulated value of 70 volts, Q_3 turns on causing Q_4 to turn on which causes the multivibrator to stop and Q_1 and Q_2 to switch off. As the voltage on C_2 drops below the regulated value, Q_3 and Q_4 switch off, the multivibrator, Q_1 and Q_2, begins cycling. L_2 and C_3 serve as a filter for power supply ripple and interference conducted via the power leads.

2.3 Amplifier Design

The amplifier circuit diagram is shown in Figure 6. The signal is attenuated at the input by the 10K ohm audio taper potentiometer. From the pot, the signal is fed to an inverting amplifier based on the LM 343 high voltage integrated circuit operational amplifier and a current amplifier based on a complementary pair of

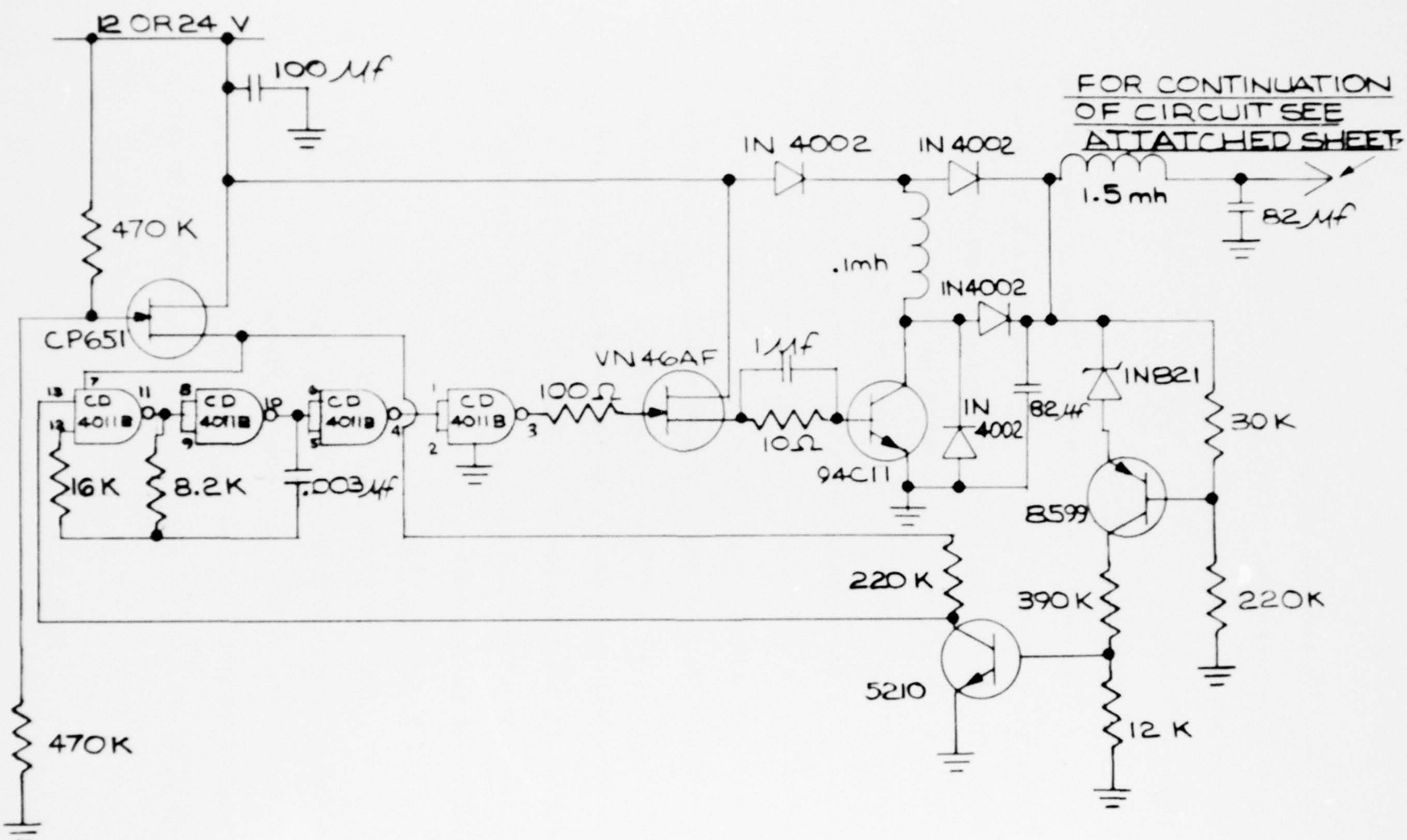


FIGURE 5

SCHEMATIC - POWER SUPPLY

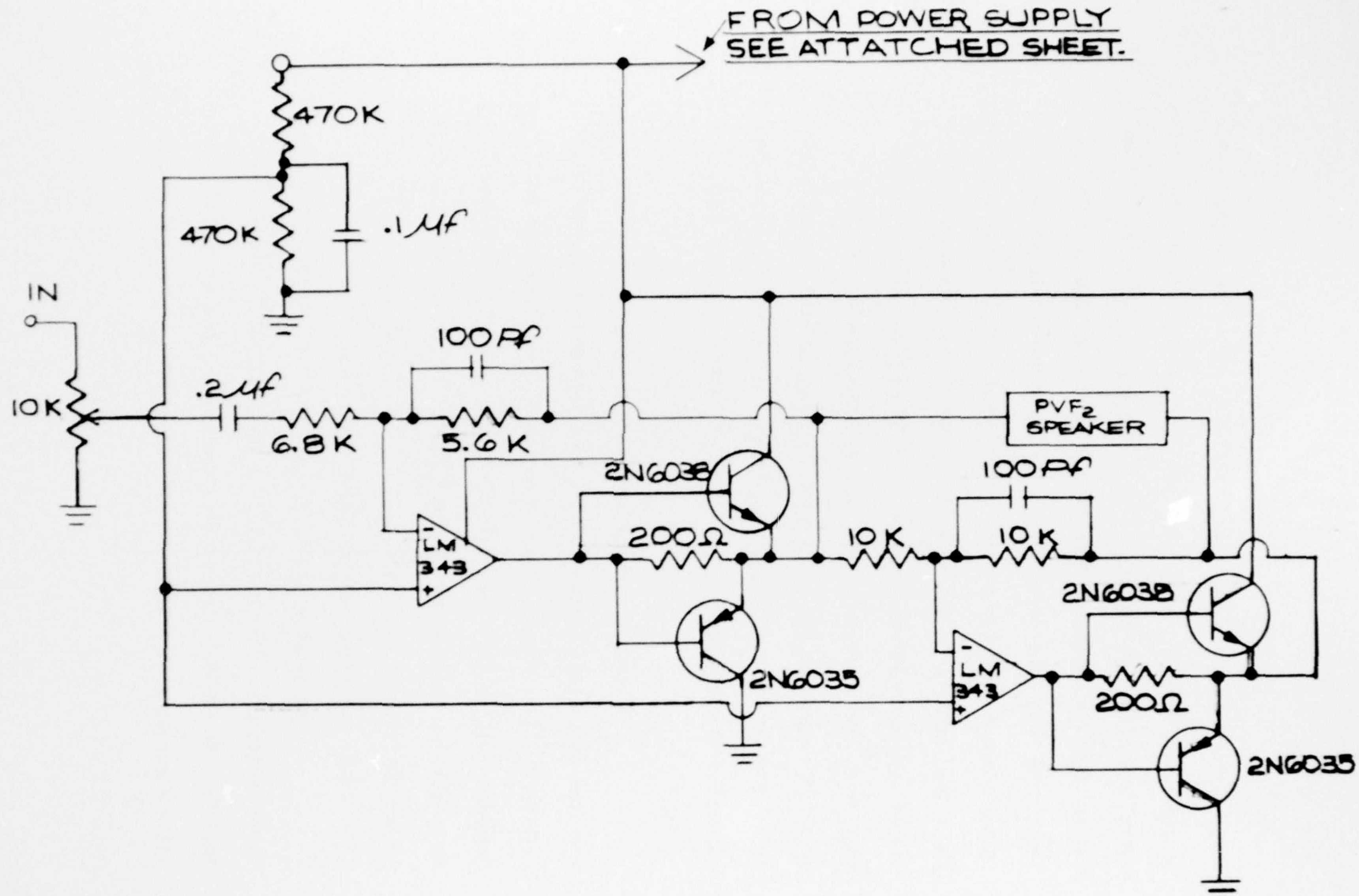


FIGURE 6

SCHEMATIC - AMPLIFIER

power transistors in a push-pull configuration. The voltage gain of this amplifier is -8.3. This amplifier drives one of the transducer leads and a second amplifier. The second amplifier is identical to the first with the exception that the voltage gain is -1. The second amplifier drives the other transducer lead so that the output signals from two amplifiers are equal but 180° out of phase. The signal applied to the speaker has twice the maximum voltage that a single amplifier would be able to supply. With a single amplifier, the maximum peak to peak voltage applied to the transducer will approach the power supply voltage. With the two amplifiers in a bridge configuration, the maximum peak to peak voltage applied to the transducer will approach twice the power supply voltage.

The output current amplifier complementary pair operates in a class B mode so that both transistors are at cutoff with zero signal input. These transistors are inside the amplifier feedback loop so that the nonlinearities associated with operating at cutoff are compensated by the feedback and high open loop gain of the operational amplifier.

2.4 Amplifier-Speaker Interface

The speaker is electrically equivalent to a .5 microfarad capacitor. This represents a very difficult load for an amplifier to drive. The current flowing to a capacitor and the voltage across a capacitor are 90° out of phase. For the output

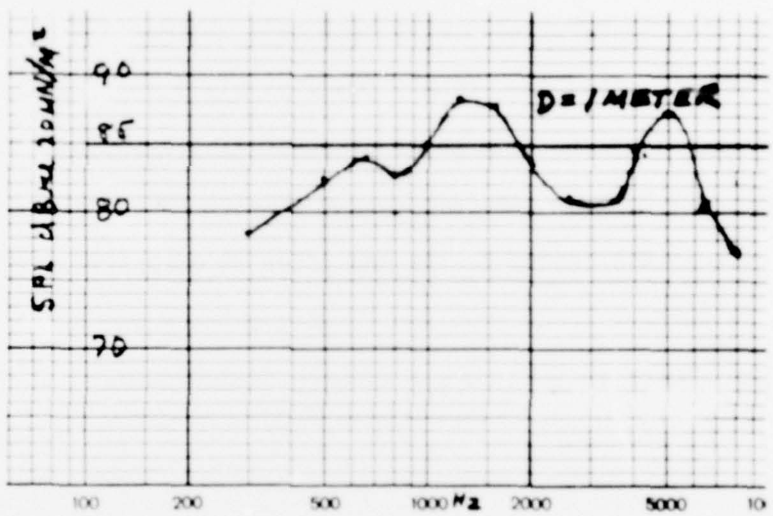
transistors, this means high current flows through the transistors at high voltages requiring the transistors to dissipate a great deal of power. The problem becomes worse at higher frequencies since the load impedance of a capacitor drops as the frequency increases.

The problem can also be described in terms of the energy stored in the capacitor. At the peak of each half cycle of signal voltage (V), the capacitor is charged to the peak signal voltage, storing energy equal to $1/2\ CV^2$ joules. As the voltage on the capacitor decreases to zero during the next quarter cycle, this energy is returned to the amplifier where it is dissipated as heat. This is repeated during each half cycle. All this energy must come from the primary power supply and is wasted in terms of useful power. The waste of power is proportional to frequency. At maximum acoustic output at high frequencies, the amount of heat dissipated by the amplifier is excessive. This results in current drawn from the 12 volt battery which can exceed one ampere at full output at high frequencies.

3.0 PERFORMANCE

As designed above, the speaker will deliver the required output level. A typical response is shown in Figure 7. Measurements were made using a calibrated Gen Rad microphone placed at 1 meter in conjunction with a B & K type 4440 gated amplifier system.

Distortion measurements made in accordance with the requirements (100 dB SPL at 10 cm) showed THD less than 2% at 400, 1000, 2000 and 4000 Hz.



4.0 GENERAL DISCUSSION

The PVF_2 speaker development program shows that it is feasible to design a loudspeaker which meets the performance and weight requirements specified. The environmental deficiencies noted in Appendix A could be eliminated or reduced to acceptable levels in another design iteration. However, the complexity of electronics in both the power supply and amplifier and the associated "Power Factor" inefficiency, in terms of primary power, cannot be significantly improved. As long as the speaker element is, in effect, a "lossy" capacitor with a reactive component much less than the resistive component, efficient matching of the amplifier will be very difficult, particularly when the primary power DC source voltage is lower than the voltage required by the speaker element. In a tweeter application such as reported in Ref (1), the 4000-8000 Hz bandwidth leads to a fractional bandwidth of .7 and transformer matching is possible. In the present application, the bandwidth is 400-4000 Hz making the fractional bandwidth 2.8. A phase (power factor) correction network, if physically realizable, would involve iron core inductances and would be inherently a voltage step-down device.

Ref (1) Masahiko Tamura, Tadahiro Yamaguchi, Takashi Oyaba, and Toshikazu Yoshimi, "Electroacoustic Transducers with Piezoelectric High Polymer Films", presented September 10, 1974 at the 49th Convention of the Audio Engineering Society, New York

Therefore, the drive must be "brute force" with its associated inefficienty.

5.0 RECOMMENDATIONS

It is recommended that the subject program not be continued unless:

(1) A careful trade-off analysis shows that the potential weight saving and absence of a cobalt containing magnet (in a dynamic speaker) overweighs the electronic complexity and excessive power drain, or

(2) An order of magnitude improvement in the activity level (stress/volt) of the PVF_2 material can be achieved.

The above in no way affects the potential use of PVF_2 in microphone or earphone use where the power levels are two or more orders of magnitude lower.

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